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ERGONOMICS AND THE PHYSIOTHERAPIST: A REPORT ON A RESEARCH PROJECT ON WORKING POSTURES

by

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THE ROLE OF THE PHYSIOTHERAPIST IN ERGONOMICS

In a series of lectures on biomechanical principles, Professor E. R. Tichauer, an authority on man-machine-task systems, stated:

"Only a few years ago, the physical work load imposed on the individual employee was much heavier than is the case today, but it was, in many occupations, fairly evenly distributed over the entire musculo skeletal system. Today, the total energy demanded from man in the performance of an industrial task has often been reduced, but stress is concentrated on individual and small components of the worker's anatomy." The techniques for combating these new stresses are found in the science of ergonomics (Hopkins 1966).

Bio-engineering, that is, engineering concerned with life, may be sub-divided into two main headings: environmental health engineering and biomedical engineering.

While the latter is concerned with the replacement of damaged parts and the design of therapeutic instrumentation, environmental health engineering (also referred to as ergonomics, human factors engineering, biomechanics) is concerned with a study of the working and living environment. Ergonomics, or its American equivalent, biotechnology, may be defined as the basic study of the human body in the man-machine-task relationship, which aims to reduce operator discomfort, fatigue and injury, and it includes all fields of safety education.

Members of the multi-disciplinary teams working in this field contribute their individual knowledge of anatomy, physiology, psychology, engineering, anthropometry and kinesiology to solve work stress problems whether at home, school or place of employment.

The physiotherapist fits into this study of the man-machine relationship because of her unique ability to analyse body movements in detail and to evaluate postural abuse during dynamic situations. Thus she can help to eliminate misuse of the body, and assist in the design of equipment and work areas so that the situations so arranged are better suited to the physical well being of the person using them.

THE PREVENTIVE ROLE OF THE PHYSIOTHERAPIST

We all know that in a rehabilitation programme, the physiotherapist not only trains the patient to function to his optimum capacity within his environment, but she also tries to adapt the environment to enable the patient to perform the maximum number of activities in the safest possible manner.

But it is not just in treating the already disabled that we should be interested. Surely we should apply these principles to the worker and his environment in an effort to prevent the development of many of the conditions now treated. How many of us take the time to examine the patient's work situation and analyse predisposing factors associated with his condition?

RESEARCH PROJECT — A STUDY OF WORKING POSTURES

Recognizing the contribution which the physiotherapist can make to the field of bio-engineering, as well as her preventive role, the Physiotherapy Department of the University of Queensland initiated a study of working postures in 1965.

The researchers realised that the effects of repetitive activity or of the isolated extra-ordinary movement, can be short-term and/or long-term.

Short-term effects:

Prolonged intermittent repetitive work, particularly if against resistance, can impose definite physical and mental stresses upon the operator. If the operator's work lay-out is not properly adapted to his anatomy and to his natural patterns of motion for that activity, then he may quickly reach, or even exceed, his limits of tolerance. (Dupuis 1959, Tichauer 1967). As a result, the physical ability to react to an emergency must surely be impaired and the possibility of accidents will increase.

Long-term effects:

The long-term effects of repetitive activity, for example, tenosynovitis, frequently interfere with the ability of the person to perform his work capably, or even, later, to work at all in that particular field. (Perrott 1961, Peres 1969.)

Consequently, with a view to making adaptations so that the operator could function to his optimum capacity, the research team decided to look at two main areas:—

(a) the operator during repetitive activity —his positioning in relation to his work layout, his working posture and his functional patterns of motion;

(b) the physical environment, including placement and arrangement of benches, tools, machines, pedals, and so on.

The first investigation concerned correct bench height for operators in the standing position, and was completed in 1967 (Lanchester 1967). Following this, the Department of Mechanical Engineering, which is carrying out research into various aspects of agricultural tractor safety, suggested that an analysis of the effect of tractor clutch design on the posture of the driver would complement some of its own work.

Included in this research is a study on accident minimisation and in their investigation, the engineers have found that, owing to prolonged use of heavy and often awkwardly placed controls and foot-pedals, the tractor operator complains of physical fatigue and occasionally aching joints by the end of the day. Since it is possible that both of these conditions influence the performance of the driver, they may be included as essential factors in the sequence of events leading to a tractor accident. The undesirable effects of a tractor accident have been classified under three main headings, *viz.*, (a) injury to persons, (b) damage to property, (c) loss of production. (Grigg, *et al.* 1968.)

The investigation within the Physiotherapy Department aims to find the clutch pedal which, on repeated use, will give rise to minimal postural abuse, including short-term and long-term effects on the operator. Since this may eliminate one of the factors leading to tractor accidents, the importance and economic relevance of this contribution can be appreciated.

The Plan

All variables in clutch design, including the three-dimensional location, the travel path and the surface features of the pedal, will be investigated. For each alteration, an analysis of the movements occurring during depression[1] of the clutch pedal will be made. By comparing and evaluating the motions of the pelvis and trunk, it should be possible to define the specifications for design of the clutch which is considered to cause minimal postural abuse.

REPORT ON THE FIRST EXPERIMENT IN THE SERIES ON TRACTOR OPERATION

The criterion on which this trial rested was that the best pedal position for the tractor operator would be that which gave rise to

[1]For the purposes of description, "depression" indicates the downward and "release" indicates the upward movement of the clutch pedal.

minimal pelvic displacement, and consequently minimal postural abuse, which is part of the total abuse of the operator.

The first variable to be investigated was the angle made by the path of the clutch pedal with the horizontal. A considerable dissimilarity has been found between angles of pedal path on the various makes of tractor in use today and it therefore seemed wise to investigate this feature first. It was hoped that for the later series of tests the clutch pedal would be arranged so that its path was at this optimum angle to the horizontal.

The aims of the trial were—

(a) to continue to develop an accurate method of measurement for use in research into working postures;

(b) to determine the feasibility of using photogrammetry as a method of measurement in these experiments;

(c) to examine the effects on body movements of varying the angle of path of the pedal during depression and release of the clutch;

(d) to compare the motions of the body during depression with those during release of the clutch;

(e) to observe any significant features which might show up on the photographs and/or graphs, and which could be relevant to the analysis and research into total body movements.

Description

Apparatus:

An experimental prototype of a tractor clutch was built by the Department of Mechanical Engineering so that certain adjustments could be made, including the distance of the pedal below, in front of, and lateral to the operator's seat, the direction of motion of the pedal and the length of the pedal travel. (See Fig. 1.)

The framework for seating was adjustable so that the specific dimensions of the operator

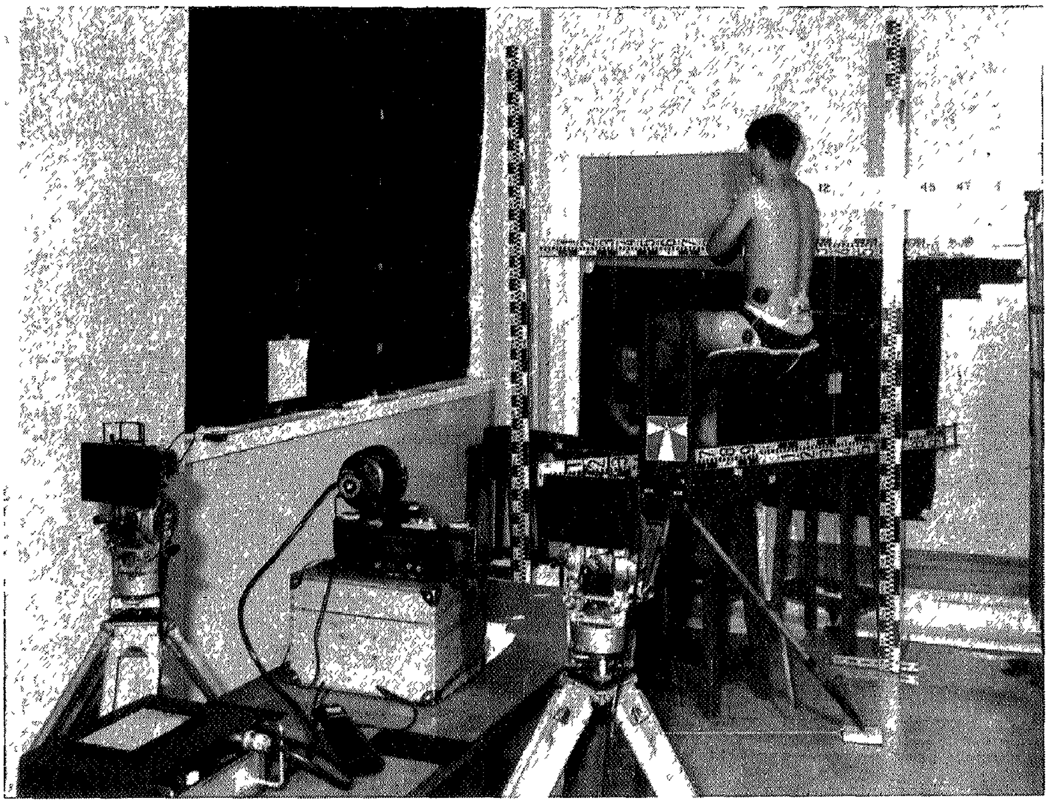

FIGURE 1.—The Arrangement of Tractor Clutch Prototype and Phototheodolites.

could be catered for, while the starting position chosen for the operator was based on the work of Floyd and Roberts.

A chair, designed by the Victorian Education Department, formed the seat surface and this was so shaped that it allowed at least 90° between erect trunk and thigh, as well as allowing hip extension to occur without discomfort to the posterior aspect of the thigh. A thin rubber cover reduced the possibility of sliding since it was decided to eliminate the back rest. Previous workers (Müller 1936, Lehmann) had depended on the back rest to gain maximum force of depression. However, it was felt that if pedal position and depression force were within the limits of the operator, it should not be necessary to use the back rest for stabilisation.

The resistance of the clutch to depression was fixed at 35 lbs., and the distance of pedal path was set at 4″. (Damon *et al.* 1966.)

The angle of the clutch pedal path with the horizontal was varied between 6° and 45°, records being made of body movements for five different angles of the clutch.

Body Markings:

In order to measure the deviation of the pelvis and leg in any direction, and the angular motion of the joints of the lower extremity during clutch depression, appropriate points on the body and tractor rig were marked, using small pieces of Reflective Transfer Film (which possesses the property of retro-reflectivity, that is, it reflects back to the light source).

Spot marks were placed on the most lateral points of the iliac crest, the greater trochanter and the lateral epicondyle of the femur, the lateral malleolus of the fibula, and the head of the fifth metatarsal. As well, a 20 cm. long plastic pointer was attached to the sacrum, having marks on its surface at 5 cm. intervals. The centre of the lateral surface of the clutch pedal was also marked for photography, so that later the movements of the body could be related to the distance travelled by the pedal.

The pointer was used on the sacrum because its length not only ensured its being focused by both cameras, but it also enabled the movements of the pelvis to be magnified for easier comparison.

Furthermore, the five marked spots on the pointer allowed the analysis of pelvic movements which would have been impossible had one spot only been used. For example, the measurement of pelvic rotation depended on the use of lines drawn through these five points.

Since the centre of rotation of motion about a joint varies during the movement (Steindler 1955), it would be impossible to locate it with any accuracy for purposes of measurement. However, it was felt that the particular points chosen for marking, situated as they were, close to the joints, were satisfactory for the following reasons:

(i) the analyses in these experiments depended on a comparison of the motions occurring at the various joints and not on the absolute location of the joint;
(ii) these points were to be constant for each alteration in clutch design; and
(iii) the skin motion over these particular points appeared to be minimal.

The Movements:

For each change of angle of the pedal path, the operator was adjusted to a previously fixed starting position.

He was allowed to depress (and later to release) the clutch pedal in his own time and was asked to hold the pedal in its depressed position for 2 seconds.

Photography of the Motion:

The Photography and the Surveying Departments of the University of Queensland determined the most effective method of photographing the movement of the points of the body for subsequent photogrammetric analysis. This technique was described by McDonald (1968).

In order to measure the three-dimensional location of the marked points, it was necessary to use a form of stereo photography. Accordingly, two photogrammetric cameras[1] (carefully positioned in relation to the tractor and spaced 1 metre apart) were used, in con-

[1]Officine Galileo Photo Theodolites, *i.e.,* cameras fixed on theodolites for levelling and positioning purposes.

junction with a centrally situated flash unit[1] set to flash every ¼ sec. during the operator's motion. (See Fig. 1.)

The photography was carried out in a darkened room. With the camera shutters open, the repeating flash unit was fired while the operator depressed or released the pedal. The resultant pair of photographs showed the positions of the reflective film spots at ¼ sec. intervals, while the moving trunk and leg remained slight blurs in the background.

Measurements

Location of the Moving Points:

Each set of two negatives thus obtained was placed in a stereo plotting instrument[2] which enabled the co-ordinates of the three-dimensional location of each successive point to be evaluated. From these results, a graph was drawn, showing the movements of the body in both plan and elevation views. (See Fig. 2.)

[1]Nikon Repeating Electronic Flash Unit.
[2]Galileo Santoni Stereo-Simplex IIC in Department of Surveying.

Evaluation of the Results

1. *Examination of the Effects on Pelvic Movement of Variation of the Angle of Path of the Clutch with the Horizontal:*

It was possible to measure directly from the graph, the movement of the pelvic pointer in the antero-posterior, vertical, lateral and rotational directions. Similar movements, for example, at the greater trochanter, the lateral condyle of the femur, the lateral malleolus and the head of the fifth metatarsal, were measured. The degree of movement of the pelvic region was related to the appropriate pedal path angle.

Table 1 is a comparison of the movements of the pelvis in two planes, produced during release of the clutch, for each change in pedal path. Similar comparisons were made for other pelvic motions, and for movements produced during clutch depression.

Angle of Path of Clutch	*Flash No.*	*Antero-Posterior Movement*	*Flash No.*	*Rotation*
		mm.		°
6°	1-6	Post. 8	1-6	Right 6
	6-9	Ant. 12.5	6-9	Left .5
		Total 20.5		Total 6.5
20°	1-5	Post. 10	1-8	Right 7
	5-8	Ant. 10.5		
		Total 20.5		Total 7
25°	1-5	Post. 8.7	1-8	Right 7
	5-8	Ant. 7		
		Total 15.7		Total 7
36°	1-6	Post. 11.5	1-7	Right 8
	6-7	Ant. 7		
		Total 18.5		Total 8
46°	1-5	Post. 5	1-5	Right 7.25
	5-7	Ant. 4.5	5-7	Left .75
		Total 9.5		Total 8

TABLE 1.—Comparison of Total Displacement of Pelvic Pointer for Varying Angles of Pedal Path.

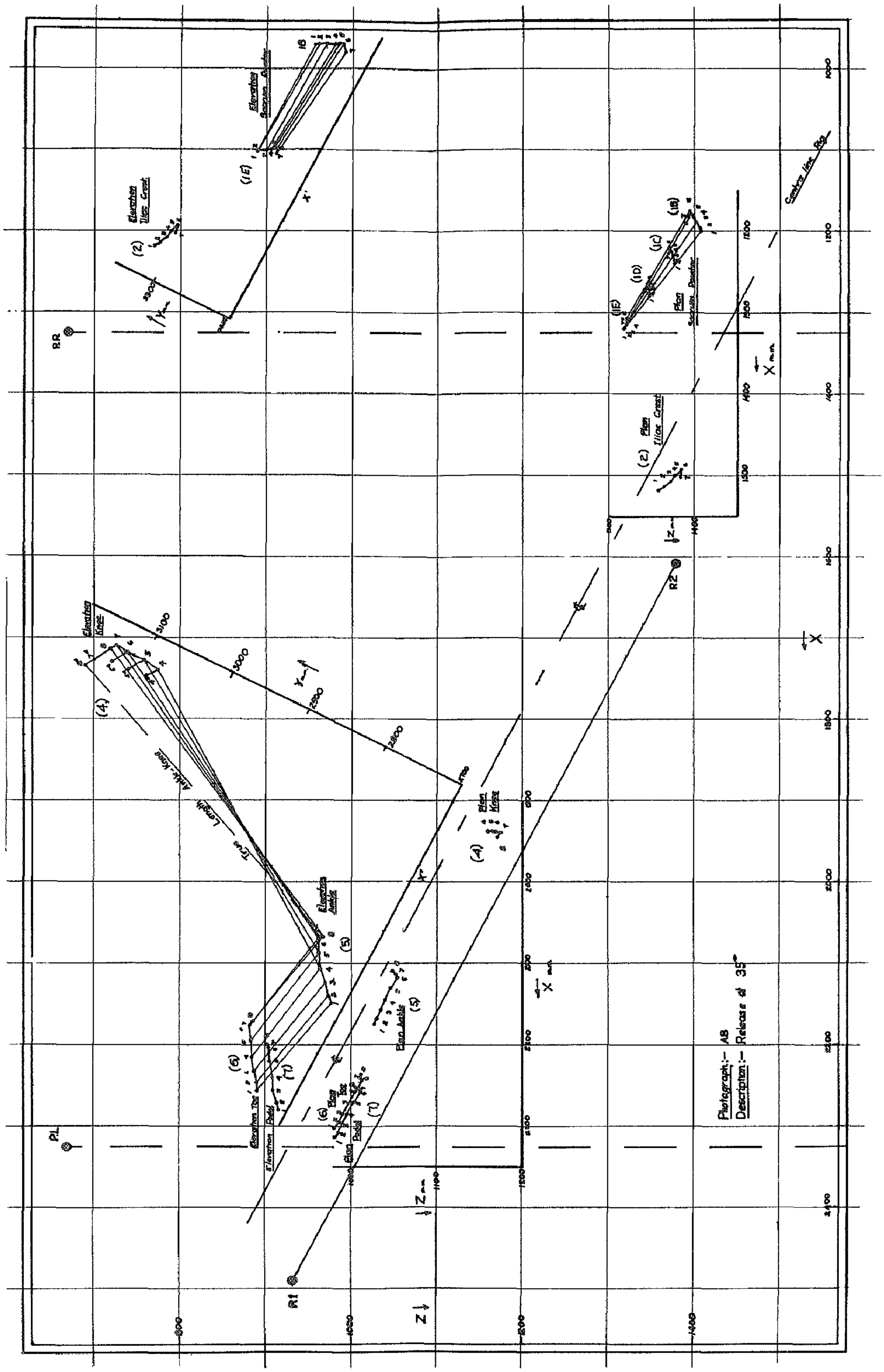

FIGURE 2.—The Location of Marked Body Points at Each Flash (1-8) During Release of the Clutch.

On examination of this table, it was obvious that for these five differing pedal conditions, the degree of pelvic motion varied. Thus, while the amount of pelvic rotation remained approximately the same, the antero-posterior movement of the pelvis decreased when the angle of pedal path increased. To assist in the interpretation of these results, a method of grading the relative importance of the various pelvic movements in the production of short-term and long-term effects on the tractor operator, is being considered.

The standard deviation of the measurements was determined by McDonald (*Ibid*) and was found to be .85 mm., which means that 95% of all measurements would be known within an error of 1.7 mm.

2. *A Comparison of the Deviations of the Various Points During Depression and Release of the Clutch:*

From the results of this experiment, it appeared that similar body movements occurred during depression to those which occurred during release of the pedal.

Examples of the pelvic motions produced when the path of the clutch was at 25° to the horizontal, are shown in Fig. 3.

It was considered that the discrepancies observed in the graphs for the other angles tested were due to the fact that there was no way of relating the actual body movement to the distance moved by the pedal. It is hoped that in future it will be possible to synchron-

Fig. 3. PELVIC MOVEMENTS — Pedal angle 25°

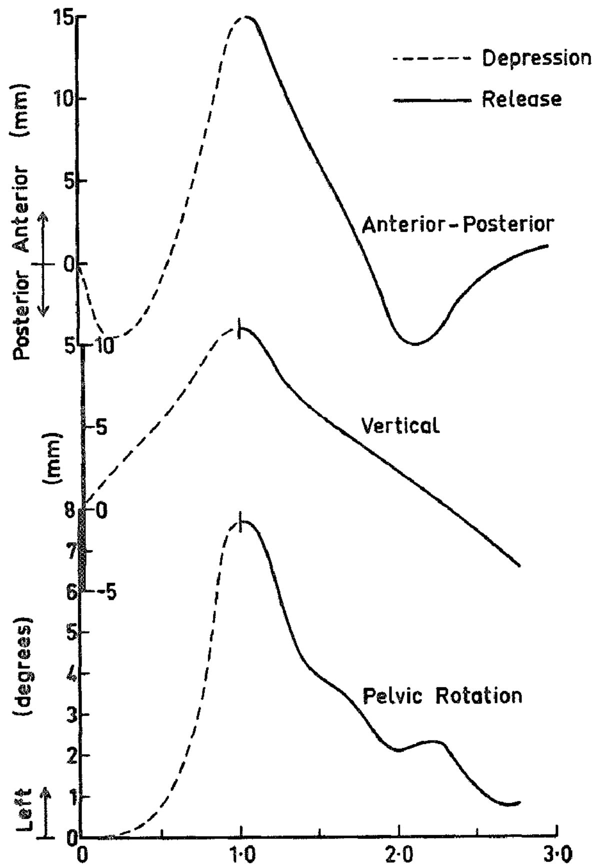

FIGURE 3.—Comparison of the Deviations of the Pelvis During Depression and Release of the Clutch.

ise all movements by increasing the intensity of one flash at regular intervals.

3. *Analysis of the Pattern of Movement of the Leg During Clutch Depression and Release:*

Measurement of the angles of motion at the hip, knee and ankle joints were made from both the plan and elevation views of Fig. 2. For example, a measure of ankle dorsi- and plantarflexion was made by joining the corresponding points at toe, ankle and knee in elevation, and measuring the angle for each flash. (See Fig. 2.) The measurements of joint motions which occurred for each change of angle of pedal path were tabulated and compared.

Flash No.	*Angles of Path of Pedal*			
	6°	*20°*	*25°*	*46°*
1	105	109	113.5	108.5
2	105	103	110.5	109
3	110	103	112.5	105.5
4	118.25	105.25	114.5	112
5	121.75	115	114.5	112
6	123	120.5		

TABLE 2.—Angular Motion at Ankle, During Depression of Clutch.

Although allowance has to be made for a rotation of the forepart of the foot during eversion (this can be calculated), it can be seen that a fairly consistent pattern of motion included early ankle dorsiflexion followed by a considerable degree of plantarflexion.

In this analysis of movement, account must also be taken of skin motion over the marked bony points. A preliminary examination indicated that the skin movement followed a consistent pattern in direction and in distance. Closer observation and recording of this will be incorporated into future experiments.

4. *Analysis of the Sequence of Movement from Foot to Trunk:*

Using an accurate timing mechanism[1] and correlating the figures for movement of body points (described in Evaluation 1) and changes in joint angles (described in Evaluation 3), it would be possible to make a complete analysis of the sequence of movement from foot to trunk. Such an analysis would give an indication of the consistency of the pattern of motion used during changing circumstances, and could be of value in determining the direction of travel of the clutch as well as the alignment of the clutch footpiece.

5. *Observation of Features Relevant to the Analysis and Research into Total Body Movement:*

It was noted that an apparently consistent pattern of flexion of the right hip occurred when the tractor operator (working without a back rest) depressed the clutch with his left foot. This movement immediately made the driver unstable in his seat. Further observations in this regard will be made.

CONCLUSIONS

It is apparent that the use of photogrammetry for measuring the three-dimensional location of moving points on the body will provide an accurate method of measurement in research into working postures. Analysis of the graphic representation of these figures will give a comprehensive picture of the patterns of motion used in each work situation. However, the method of interpretation has yet to be defined, and to this end, the possibility of devising a system of rating the relative importance of the several effects of trunk and pelvic movements on the physical well

[1]Such an arrangement is at present being devised by the Photography Department, University of Queensland.

being of the operator is at present being investigated. When this has been done, the most suitable angle of clutch pedal path can be described.

It is hoped that the solution to the question of the design and placement of a tractor clutch pedal will be evident on the completion of experiments using the methods described here.

Since the results should indicate the optimum relationship between operator and foot pedals, they may be applicable to industrial situations involving a similar work pattern.

It is hoped that the technique of using photogrammetry to measure the three-dimensional location of moving points may prove valuable to other studies in the ergonomics field.

Besides providing some of the information required for the design of working and living areas, the detailed analysis of human movement should improve the understanding of the mechanism of injury and disability and should play an important part in the prevention of further injuries. As well, physiotherapists stand to gain a tremendous basic academic knowledge of body movement and of joint force systems in the normal and in the disabled.

SUMMARY

The role of the physiotherapist in ergonomics and in the prevention of disabilities is discussed, showing the factors which led to the study of working postures within the Physiotherapy Department of the University of Queensland. The economic relevance of the contribution made by a physiotherapist to a research team investigating tractor safety, is indicated and the value of the specific aim, namely, to find the tractor clutch pedal which on repeated use will give rise to minimal postural abuse, is stated.

The technique of using photogrammetry as a method of measuring body movements for research into working postures is described in detail and its accuracy recorded.

The first experiment in the series on tractor clutch operation is described and the results evaluated. Modifications to the experiment and some investigations that will assist in the interpretation of these results are indicated.

Suggestions are made for the use of the photogrammetric technique of measurement in other studies in ergonomics and of the application of the optimum relationship between operator and foot pedals to other industrial situations.

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